DEPARTMENT SUMMARY

The Department of Mechanical Engineering's research effort comprises activities in five main areas: the thermal/fluid sciences; solid mechanics and vibration; dynamic systems and controls; material sciences; and total ship systems engineering. Individual programs of relevance to the Navy continue to advance the state of knowledge in each of these areas. Results of these research programs are published in student theses, NPS technical reports, in technical papers given at various national and international conferences, and are also published in a wide variety of scientific journals. The individual programs associated with each faculty member are described in the following overviews, which correspond with the main discipline areas of the Department.

Dynamic Systems, Controls and Robotics

Professor Anthony H. Healey was active in furthering the technology of Autonomous Underwater Vehicles (AUV) and land based robot systems for minefield and unexploded ordnance clearance. In particular, the *Center for Autonomous Underwater Vehicle Research,* directed by Professor Healey, has facilities that include the AUV laboratory in Building 230, housing a 20' by 20' 6' deep vehicle systems test tank, that will support autonomous hovering maneuvers and high frequency imaging work of the AUV *Phoenix*. *Phoenix*, a testbed vehicle, has been designed and operated by the Center. In late 1997, a major advance was made towards performing the first experimental operation in open water outside the Monterey Harbor in the Monterey Bay. Major software developments were performed including the purchase and networked integration of a pentium-based processor running the QNX operating system in the *Phoenix* vehicle. The AUV has been equipped with a 900 MHz radio modem for communications between shore and vehicle when surfaced. The vehicle has a new propulsion system using two 1/4 horsepower DC brushless motors and larger propellers giving an expected forward speed of 3-4 knots when submerged.

International visitors to the Center included Professor Antonio Pascoal, and his doctoral student Carlos Silvestri from the University of Lisbon in Portugal. Additionally, Jose Miguel and Alfredo Martins, Ph.D students from the University of Porto, as well as NPS students, have worked with Professor Healey during this last year in the development of Petri Net methodology for the discrete event control of AUV missions. Professor Pascoal is now spending his sabbatical year in the Center. A new program this year has been funded by ONR to develop software for the Navy's 21UUV Tactical Size Vehicle that will automatically detect subsystem faults and make appropriate control reconfiguration. Also new is an ONR funded program to develop advanced controller architectures and concepts as part of a Multi-University Research Initiative, joint with Virginia Polytechnic Institute and the Florida Atlantic University. This program also focuses on fault tolerant control architectures and in particular studying the vehicle motion control in very shallow waters with wave conditions.

The effort has been funded during 1997 by the Office of Naval Research, the Naval Explosive Ordnance Disposal Technical Division, Florida Atlantic University, and Naval Surface Warfare Center-Coastal Systems Station, Panama City.

Professor Morris Driels' research focussed on the area of target acquisition, and was conducted for two major sponsors: (1) U.S. Army (White Sands Missile Range) and (2) Joint Technical Coordinating Group (JTCG). The work may be summarized as follows:

JTCG Projects: JTCG currently has a paper manual allowing users to predict the probability that a target they are planning to attack can be detected in sufficient time for the attacking aircraft to be maneuvered and the weapon released in time for a successful strike. The manual only contains data, and no algorithm, therefore it cannot be updated for newly developed weapon systems and aircraft. The research involved discovering the underlying analytical basis for the data presented in the manual, updating this basis to reflect the latest available methodology, and encapsulating the results in a stand alone computer program to replace the current manual. This model was developed in FY97 and presented to the JTCG A/S community for their review and approval. Preliminary planning was done for the incorporation of this TA module into JAWS, an FY98 task. In addition, a computer tool was produced which enables operational users to specify the nature of the target they are attacking, the terrain in which the target is located and the cultural features surrounding the target. The tool then determines those sectors of approach that will be obstructed by, for example, surrounding buildings or specific terrain features. Given the location of the target in the world and the sensors used for detection, the tool provides users with target/background visible/thermal contrast values as a function of time of day. Finally, the tool superimposes acquisition, unmasks and delivers contours superimposed on imagery of the target area, and generates images of the target at the weapon release point. The program is applicable to airborne or ground based weapon systems used against ground targets.

U.S. Army Projects: In planning joint ground operations, each participant should use similar models for all phases of the operation in order to correctly predict the outcome of the action. In support of this, the ABCA (America, Britain, Canada, Australia) group has decided to adopt common models to estimate the outcome of certain forms of ground combat. In the area of target detection, standardized models will be needed in the areas of visual, infrared and video target observation, as well as models to predict observer search times and models of the human visual and cognitive systems. The research collated selected models in all of these areas, together with an analysis of those conditions in which the models are intended to perform. The resulting handbook allows users to evaluate and select appropriate models for the scenario under consideration and provides an analyst manual for that models operation. The U.S. Army does not have a target detection model designed specifically for use in the visible spectrum. Instead, they use a model called ACQUIRE, which was developed solely for use in the IR region, but has been adapted for the visible spectrum. ACQUIRE has been shown to be a poor predictor of performance in the visible spectrum for some scenarios. The U.K. has a very good visual performance model called ORACLE, but it is proprietary to British Aerospace. The research involves an analysis of the ORACLE model and, in particular, if the algorithmic basis could be found in the open literature. If this could be done, a U.S. version of ORACLE (to be called DELPHI) could be developed and used. The result has been the development of a foveal optical channel which reproduces ORACLE's results with a high degree of accuracy. All algorithms have been obtained from public domain sources.

Associate Professor Fotis A. Papoulias conducted research on maneuvering and control of submersible vehicles in varying operational specifications and environmental conditions. The objective of this work is the development of a control strategy, which allows for on-the-fly reconfiguration of integrated guidance and control strategies of an underwater vehicle in shallow and littoral waters. In view of the uncertainties inherent in the littoral environment, an effective control strategy will need to monitor execution and modify plans on-line as needed. For this reason, an appropriate seamless integration of relevant planning, guidance, and control functions is necessary. A formal approach to the integration of guidance and control functions in a shallow water environment is under development in order to achieve an increased system operability, performance, and mission success.

In addition, Professor Papoulias performed an analysis of roll stabilization schemes for a given class of surface ships to be used as mobile radar platforms. A careful analysis of the advantages and disadvantages of each system, in conjunction with the ship's operational requirements resulted in a final recommendation of a bilge keel stabilization scheme. The results demonstrated the vast impact on ship operability that such a roll stabilization system has.

Additional studies were performed with respect to current dynamic stability criteria for surface ships and their parametric relationship to hull form geometric properties. A systematic procedure for varying hull properties was initiated. It was shown that it is possible, in principle, to obtain an approximate expression relating ship dynamic stability to basic hull geometric properties. Since such geometric properties are easily obtained for a given ship type, the results of this work can be used as both design and assessment tools, in particular during salvage operations.

Fluid Dynamics, Heat Transfer, and Turbomachinery

In 1997, Distinguished Professor Turgut Sarpkaya directed five research projects, sponsored by the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), and the Office Naval Research (ONR).

The first NASA project is basic and applied *continuing* research towards the understanding of the phenomena resulting from the breakdown of vortices in trailing vortices and in a turbulent flow field, created by a round swirling jet issuing from a nozzle, for various swirl ratios, Froude and Reynolds numbers, and deep and shallow modes, using a three-component LDV system and laser-induced flow visualization.

The second NASA project deals with an in-depth *continuing* analysis of velocities, circulations, and decay histories of a number of trailing vortices generated by large aircraft during field tests in Memphis, TN, towards a clear understanding of the decay mechanisms. The complex circumstances governing the pre-roll-up history and the post-roll-up state of the trailing vortices have been clarified and the flight-separation times have been calculated for various domestic and foreign aircraft.

The first ONR project is a *continuing* investigation to carry out combined analytical, numerical, physical, and thought experiments to devise a physics-based model for the prediction of flow-induced unsteady forces on bluff bodies immersed in time-dependent flows. The new model, based on a sounder scientific rational, is expected to replace the current models and offer greater universality and higher engineering reliability, particularly in the so-called drag-inertia regime.

The second ONR project is a *continuing* investigation of the spray generation from bow-sheets. A series of new experiments have been designed to understand the influence of several competing internal/external influences such as turbulence, gravity, surface tension, liquid-sheet geometry, surface shear, roughness of the contact surfaces, velocity distribution in the sheet, and pressure fluctuations within and outside the sheet to understand, model and predict droplet and spray formation. The technological importance (IR signatures) and intellectual challenges (stability of a two-phase flow) presented by this nontrivial flow phenomena demand a scientific understanding of its physics through judiciously conceived physical experiments and numerical analyses which are now underway.

The NSF project is *continuing* fundamental research toward the understanding of the characteristics of the conical vortex breakdown discovered by Professor Sarpkaya. Trailing vortices, swirling flows in pipes, vortical flows above sweptback wings at large angles-of-attack, flows in closed containers with a rotating lid, and columnar vortices in atmosphere may experience breakdown. Where, how, and under what circumstances does this transformation occur in *viscous* vortical flows constitute the essence of the breakdown problem.

The foregoing five *continuing* sponsored fundamental/applied research projects resulted in two published papers, five conference papers (which will be published in archival journals in 1998), and three conference presentations.

Professor Matthew D. Kelleher has been continuing studies to model the effects of fire on the thermal environment of missiles in the launch systems of surface combatant ships. Distributed lumped capacitance and thermal resistance models have been formulated to obtain time response behavior of a missile in a canister within a cell in the Concentric Canister Launcher (CCL) System. More detailed computational fluid dynamics models of the fire induced environment within these systems is also being used to determine the effects on the missile of fire in the vicinity of and within the missile magazines. It is very important that an understanding of the propagation of fires in the various missile magazines be developed and that some means be developed to apply that understanding to the design of future combatants and to the development of fire fighting procedures. The thermal effects in the CCL due to a fire in an adjacent compartment have been simulated using computational fluid dynamics. A commercial code developed by CFD Research Corporation (CFDRC) has been used to implement the process.

Professor Kelleher has also been conducting a study to evaluate the Military (Mil) Standards used in the procurement process for acquiring tactical advanced computers. The standards dealing with temperature, humidity, altitude, salt fog and other environmental conditions have been examined and compared to existing commercial standards. It has been found that in many cases the commercial standards are as stringent as the Mil Standards. An analysis and computer simulation of the thermal performance of the TAC-4 Rugged Rack (CLIN 0003AA) is being performed. A methodology for determining the effect of air flow through the rack system on the temperature of critical components mounted in the rack, including the processor, the power distribution unit (PDU), the monitor, and the uninteruptable power supply (UPS) is being developed. The model will be used to perform parametric studies accounting for convection and conduction cooling. The effect of fan capacity and ambient cooling air temperature will be evaluated

Assistant Professor Ashok Gopinath has been conducting research in time-averaged thermo-fluid phenomena induced by strong acoustic fields as part of an ongoing program on thermoacoustic transport sponsored by two grants from the NASA Microgravity Program. The goal is to obtain a better understanding and to quantify the thermoacoustic behavior in strong zero-mean oscillatory flows with potential application to the design of heat exchangers in thermoacoustic engines. Much fundamental insight has been gained into the role of various properties and parameters in the flow using analytical means. With relevance to thermoacoustic engine design, this has helped deduce optimal stack spacing and location that would maximize the performance of such engines.

Also, during CY97, an experimental project was carried out to explore the use of a standing wave acoustic field in a high-pressure gas to simulate the hydrodynamic wave loading on an offshore structure. Data gathered for lift and drag forces on a cylinder under such loading conditions corroborate well with existing data in the literature. The technique appears to hold promise for future testing under larger values of the parameter regime and is in the process of being patented.

Assistant Professor Knox T. Millsaps has been conducting an analytical and experimental investigation on optimizing the angular acceleration of a long, slender rotor passing through critical speed to minimize the amplitude of lateral vibration as well as the transmitted structure borne acoustic signature. Results from this study show that the operation of various acceleration schedules can be well understood by consideration of the instantaneous power transfer rate from the unbalanced inertial forces to the total system energy (potential plus kinetic energy).

An experimental program to measure the synchronous (at rotor speed) pressure forces on a compressor rotor of a gas turbine due to non-uniform rotor blade tip clearances was conducted. High frequency response Kulite transducers were mounted in several axial and circumferential locations over the second rotor row of an axial compressor. Results from this study show that large amplitude synchronous forces relative to blade passing perturbations occur. Measurements were made on an “as is” rotor, a uniform tip clearance rotor, and a rotor with an imposed first harmonic in tip clearance. A rational correlation for rotordynamic forces versus the degree of non-uniformity of tip clearances was developed.

A method for determining a diesel engine’s cylinder firing pressures, based on instantaneous output shaft speed, is being developed. A high fidelity torsional engine model was developed and calibrated for a 3-cylinder, 2-stroke diesel engine. Experimental measurements of near instantaneous speed fluctuations from this engine were made and good agreement was found between the measurements and the model over a range of speeds and applied torques. A new method for representing the speed fluctuations using integrated deviation from a constant speed shaft phasor was developed. This method proved to be very effective in identifying cylinders with low firing pressures.

An analytical and experimental research program into enhanced mixing technology for gas turbine exhausts for surface ship, IR signature suppression is being conducted. Methods to increase secondary flow into mixing eductors (ejectors) and, hence, reduce the mixed-out plume temperature are being investigated. Multiple high aspect ratio slot primary nozzles are being investigated along with enhanced axial vorticity generated by lobed mixing nozzles. A 1-D lumped parameter model is being used for preliminary design calculations.

Distinguished Professor Emeritus Paul J. Marto completed his research on condensation heat transfer enhancement by finishing his NSF-funded project on co-existing filmwise and dropwise condensation of steam on horizontal tubes. During the course of this investigation, a new hydrophobic monolayer coating was utilized which may be very attractive for use in large condensers of the future. Professor Marto also completed writing a chapter on condensation heat transfer for the new edition of the *Handbook of Heat Transfer*.

<u>Solid Mechanics, Shock, and Vibration</u>

Professor Young S. Shin continued his investigation on response of Naval structures to underwater explosion under the sponsorship of the Naval Sea Systems Command (NAVSEA), and the Naval Surface Warfare Center (NSWC)-Annapolis Detachment. For the NAVSEA project, modeling and surface ship shock simulation of DDG-53 has been conducted. This task is a part of team project consisting of NAVSEA, NSWC, Electric Boat, Weidlinger Associates, Gibs & Cox, and NPS. The task includes investigating whether the ship shock modeling and simulation can predict the dynamic transient responses of ship system and subsystem structures accurately. The analysis takes into account the effects of the fluid-ship structure interaction and cavitation effects on a surface ship model (DDG-53) due to a large scale underwater explosion. NSWC-Annapolis has been developing the Advanced Lightweight Influence Sweep System (ALISS). Professor Shin has performed the shock and vibration analysis of _ scale GA superconductor magnet model to assess the survivability in a severe environment.

Professor Shin has also been conducting four additional research projects: (1) Survivability of Shipboard Personnel Subjected to High Amplitude, Low Frequency Shock Induced By Underwater Explosion sponsored by NAVSEA; (2) Age-Reliability Analysis of Shipboard Repairable Systems sponsored by NAVSEA; (3) Frequency Modulation Approach for Machinery Noise and Vibration Suppression sponsored by the Office of Naval Intelligence and; (4) Evaluation of Environmental Requirement, Test Methods and Standard for Tactical Advanced Computers: Shock, Noise and Vibration sponsored by the Space and Naval Warfare Systems Center-San Diego (formerly NRaD).

Associate Professor Young W. Kwon worked on four sponsored projects during this reporting period. They were sponsored by the Air Force Phillips Laboratory, Marine Corps Systems Command, National Naval Medical Center, and Naval Surface Warfare Center, respectively. Two of them were continuing projects from previous years, and the other two were new projects. The first project, funded by the Air Force Phillips Laboratory and NPS, was to investigate damage/cracking in solid rocket propellants. In order to predict and understand the damage/cracking process, a numerical modeling and simulation technique was developed using the micro/macromechanical approach and damage mechanics. Using this technique, the effect of applied strain rate on damage/crack initiation and growth were investigated. Experimental data also validated the numerical technique. The second project was the biomechanical research sponsored by the National Naval Medical Center. The effort was placed on determining the instantaneous axis of rotation of the human cadaveric knee before and after the anterior cruciate ligament injury. A mathematical derivation was developed using the data measured from the 3-D motion device developed from previous years to determine the instantaneous axis of rotation. This study made a significant contribution to finding the common motions of different human knees. The cumulative research from this project gave Professor Kwon an “Excellence in Research Award” from the American Society of Sports Medicine this year.

The third project, sponsored by the Marine Corps Systems Command, was a body armor project. The emphasis was placed on evaluation of counter-mine boots currently available for U.S. soldiers against anti-personnel mines. The research characterized the material behaviors of all the materials used in the boots, and a finite element analysis was conducted to study the effectiveness of the boots on the lower extremity injury of soldiers under the M-14 anti-personnel mine. The last project, funded by Naval Surface Warfare Center, was to derive a new shell element for the finite element analysis which could be used to simulate progressive failure of metallic structures, like ship hulls, subjected to underwater explosion. The new shell element could have pressure variation through the shell thickness. This is important to implement Gurson’s constitutive equation into the shell element so that microvoid growth can be modeled as progressive failure.

Associate Professor Joshua H. Gordis is conducting research in several areas of structural dynamics, vibration, and acoustics. In structural synthesis, a family of analytic methods have been developed which allow the direct calculation of modified dynamic response of structural dynamic system computer models which have been arbitrarily modified and/or combined with other models. These methods are distinguished by their ability to treat modifications of arbitrary size, distribution and damping, and that the methods provide a highly efficient and exact solution in all cases, where the synthesis is independent of model size. The time domain synthesis formulation is recently being extended to address local nonlinearities in large linear systems. The formulation provides an order of magnitude reduction in the time required to solve large, locally nonlinear structural dynamics problems. Work in acoustics focuses on the frequency dependent diffraction of acoustic waves due to obstacles such as wedges and plates. The goal of this work is its application to architectural acoustics.

Research is also being performed in structural system identification, where deficiencies in math models are identified through the use of measured dynamic response data. Recent results include the identification of a non-standard set of eigenvalues which provide additional independent data with which to tackle the underdetermined system identification problem. The system identification methods are being applied in the area of structural damage detection, which seeks to uncover structural damage in components using measured dynamic response data.

Research and development continues in the structural dynamic analysis of the Boeing-Sikorsky RAH-66 Comanche helicopter. Working with two additional faculty members, several modifications to the design of the Comanche aft fuselage were developed and shown, using finite element analysis, to provide an 18% increase in fuselage torsional stiffness, which is a critical quantity with respect to airframe structural dynamics and flight-worthiness.

Ship Systems

Associate Professor Charles N. Calvano’s work with the Institute for Defense Analyses (IDA) continued in 1997, with emphasis on documenting the work in a paper to be presented at the American Society of Naval Engineers (ASNE) Annual Meeting in March 1998. The Navy partially adopted the principles of Operationally Oriented Vulnerability Requirements (OOVRs), espoused in this work, in the first draft of the SC-21 Operational Requirements Document (ORD) which includes them in some ship performance areas. Adoption of this approach is expected to increase the likelihood that ships will be able to “fight hurt” after receiving expected levels of damage.

OPNAV is interested in ongoing survivability research at NPS and in establishing a formal research center. In late FY97, the physical site for conducting such work was established in the Total Ship Systems Engineering Design Lab and survivability research by Professors Calvano and Papoulias was funded during 1998. To investigate the characteristics of damaged Navy ships in conditions of progressive flooding, a CRADA with AHT Inc. to use their simulation software (SIMSMART®) on the problem was initiated. The CRADA is presently under review by ONR and will become part of the first year’s effort of the Survivability Research Center.

As part of the Navy’s Revolution in Military Affairs (RMA), the CNO’s Strategic Studies Group is exploring the positive impacts on task force survivability of large numbers of small ships with robust communications and distributed combat capabilities. Areas of exploration suggested include identification of missions and tasks for the ships, characterizing ships capable of those missions, and exploring the role of ship and combat systems modularity in making such ships more affordable. Professor Calvano is exploring the ship characterization and modularity aspects of the work while Professor Hughes of the Department of Operations Research addresses the missions and tasks.

Exploration of the Navy utility of non-traditional hull forms continued in thesis work on the stability implications of tumblehome hulls. This hull form has long been known to have stability weaknesses but was only recently seen to have useful radar cross section (RCS) characteristics which improve survivability. In order to trade off between the stability and improved RCS, the thesis quantified the degree of impact of tumblehome on stability.

Materials Science

Professor Terry R. McNelley continued work on a program of research into processing microstructural refinement and fracture toughness enhancement of particle-reinforced metal matrix composites with sponsorship by the Army Research Laboratory and Army Research Office. Initial work in this area was conducted with support from Duralcan-USA, a composites manufacturer located in Detroit, MI, under a CRADA agreement. In this initial effort, the feasibility of enhancing composite ductility by controlled thermomechanical processing was demonstrated. Under the Army-sponsored effort, the mechanisms of particle redistribution have been examined both experimentally and by finite element modeling of large strain deformation effects on the particle distribution. Deformation at elevated temperatures and under conditions promoting particle stimulated nucleation of recrystallization within particle clusters may facilitate redistribution of the particles and aid in homogenization of the particle distribution. Recent developments are currently being applied to the study of recrystallization in such materials and, in particular, to the nature of grain boundaries developed in relation to the processing conditions. Also, it has been shown that well distributed particles and a highly refined matrix grain structure contribute to improvements in the strength-toughness relationship in these materials. Indeed, strength-toughness combinations exceeding those characteristic of the unreinforced matrix are attainable by properly designed treatment of fully processed composites. In a joint effort with researchers at the CENIM Laboratory in Madrid, Spain, similar computer-aided electron diffraction analysis methods have been employed to investigate the mechanisms of recrystallization and grain boundary development in several superplastic aluminum alloys. Materials have been examined following various thermomechanical processing and deformation histories. Alloys such as Supral 2004, Al-10Mg-0.1Zr and Al-5Ca-5Zn transform to a superplastically enabled state by a continuous recrystallization reaction. High-angle grain boundaries develop as grains subdivide due to dislocation reaction during large-strain deformation. Recovery during annealing results in further changes that occur gradually and homogeneously throughout the deformation microstructure and the stable end orientations in the deformation texture are largely retained. Grain boundary misorientation distributions are bimodal in character and reflect both dislocation and texture-related boundaries. Alloys such as 5083 and 7475 transform via recrystallization processes involving the heterogeneous formation and subsequent growth of grains by the migration of high-angle grain boundaries. Now, the stable end orientations of the deformation texture are replaced by recrystallization components and misorientation distributions tend to be random in nature, reflecting the role of dispersed particles on the recrystallization process.

During 1997, the members of Professor Alan G. Fox's research team in the Center of Materials Science and Engineering were Professor E.S.K. Menon, Dr. Martin Saunders (NRC Research Associate), Mr. R. Y. Hashimoto (Materials Engineer) and Graduate Students, Lieutenants F. Maldonado, R.L. Johnson, and J.F. Dill.

In 1997 these group members have been pursuing various projects. Work has been continuing in collaboration with the Carderock Division of the Naval Surface Warfare Center and the Naval Research Laboratory on studies of the mechanical properties of Navy high strength steels and their weldments so that new weld consumables and parent steels for Naval applications can be developed. As in 1996, projects were undertaken in collaboration with the Naval Air Warfare Center, Patuxent River, MD. These concerned the microstructural characterization of new high temperature intermetallic alloys (including TiAl and NiAl) using new methods in x-ray and electron diffraction. Also during 1997, a new project on the topic of underwater wet welding was started in collaboration with the Underwater Ship Husbandry Division of the Office of the Director of Ocean Engineering/Supervisor of Salvage and Diving, Naval Sea Systems Command.

In 1997, the Fox group presented and published twelve conference papers (one invited) and three journal articles were accepted for publication. In addition, two invited presentations (without proceedings) were given by Professor Fox at the Sagamore XII Conference and to the Materials Science Department at the University of Southern California.

DEPARTMENT SUMMARY

Associate Professor Indranath Dutta's current research efforts are concentrated in the areas of metal-matrix composites and electronics packaging materials science. In the area of composites, there are two programs. One is on creep and thermal cycling behavior of fiber reinforced metal-matrix composites at elevated temperatures, which is currently supported by the National Science Foundation. During 1997, the emphasis was on identifying constitutive laws for interfacial deformation. To this end, experimental and modeling of interfacial deformation during fiber pushout testing was conducted. The second program is on the improvement of fracture toughness of discontinuously reinforced aluminum (DRA) composites via innovative processing routes, and was supported in 1997 by the Army Research Office and Wright Patterson Air Force Base. During 1997, in an extension of previous work, it was demonstrated that both fracture and strength properties of DRA can be improved relative to unreinforced aluminum if the process and microstructural conditions are precisely understood and controlled. In the area of electronics packaging, Professor Dutta is investigating new methods to improve adhesion between metallizations and CVD diamond substrates for hybrid micro-electronics packaging applications, in collaboration with Professor E.S.K. Menon. Also, Professor Dutta is initiating a new research program on liquid phase sintering of ceramics (LPSF) in collaboration with Professor A. Gopinath.